SOUND DIFFUSER WITH LOW FREQUENCY SOUND ABSORPTION

BACKGROUND OF THE INVENTION

The present invention relates to a sound diffuser with low frequency sound absorption. When sound is incident on a surface, the sound energy may be absorbed or reflected. The reflected sound can either be concentrated in one direction, in the case of specular reflection, or spread in many directions when it is diffused. Historically, sound treating surfaces have been designed either to be absorbing or diffusing, but a surface that can incorporate some absorption while also diffusing any reflected sound may be of use to designers. Applicants and Applicants' Assignee have developed binary amplitude diffusers (U.S. Patent No. 5,817,995) as well as a diffuser known by the Trademark "DIGIWAVES" (U.S. Patent No. 6,112,852) which combine diffusion with absorption. However, a need has developed for a hybrid diffuser-absorber that divides absorbed sound from diffused sound based upon a transition frequency. It is with this thought in mind that the present invention was developed.

RPG DIFFUSOR SYSTEMS, INC. has previously disclosed a mounting method for its diffusing devices that provides low frequency absorption, by providing slots or spaces between diffusing elements. These spaced diffusing elements are mounted with a rear air cavity including a porous absorption panel on the rear surface

of the diffusing device. The present invention distinguishes itself from this mounting method, by providing a series of means, via holes, slots or microperforations, for low frequency absorption within the body of the diffusing device, as opposed to between devices, thereby providing diffusion and absorption in a self-contained device.

SUMMARY OF THE INVENTION

The present invention relates to a sound diffuser with low frequency sound absorption. The present invention includes the following interrelated objects, aspects and features:

(1) In a first aspect, the present invention may be practiced by performing modifications on existing diffusers as they are known in the prior art. In this regard, means are incorporated into a diffusive surface to provide sound absorption below a pre-set frequency.

(2) In a first example of such a modification, Applicant's Assignee manufactures a diffuser known by the registered Trademark "FLUTTERFREE®". The "FLUTTERFREE®" diffuser may be modified by creating through-holes in certain wells of the diffuser that allow sound to travel through the diffuser to the rear thereof where an absorptive material may be located. The absorptive material may be made of any suitable material such as fiber glass, foam or mineral wool. As will be described in greater detail hereinafter, the cut-

off frequency between diffusion and absorption may be "tuned" or adjusted by varying the total volume of holes made within the diffuser, and by determining the particular cavities (and their depths) which are chosen to be modified through the provision of holes.

(3) In a second embodiment of the present invention, a two-dimensional diffuser may be modified through the provision of holes or slots. As an example, Applicant's Assignee's patented "SKYLINE®" diffuser may be modified through the provision of holes or slots formed in the narrow channels between two-dimensional blocks used to create "wells" therein. As in the case of the "FLUTTERFREE®" diffuser, the frequency cut-off between diffusion and absorption may be suitably adjusted by adjusting the locations of the holes or slots and the total volume of holes.

(4) In a further example, a "QRD®" diffuser may be modified by placing holes or slots within one or more of the wells thereof. Again, as before, the frequency cut-off between diffusion and absorption may be suitably adjusted through holes or slots formed in particular wells and by adjusting the volume of holes within the diffuser as a whole.

(5) A further example of the teachings of the present invention may be applied to a diffusive surface which may be best described as a compound curved shape. Such a shape may be modified through the provision of holes and/or slots formed in various

regions of the surface thereof with the cut-off between diffusion and absorption being adjusted based upon the locations of the slots or holes and based upon the total volume of slots or holes as compared to the entire surface area of the diffusive surface.

(6) As explained hereinabove, with regard to the "FLUTTERFREE®" diffuser, in each embodiment of the present invention, holes or slots are formed in a diffusive surface and lead sound waves to an absorptive surface. The perforations can be any shape or size and by varying the perforation and cavity size, the inventive devices may be "tuned" to begin to absorb sound below a desired chosen frequency.

As such, it is a first object of the present invention to provide embodiments of a sound diffuser with low frequency sound absorption.

It is a further object of the present invention to provide such devices wherein the diffuser employed is that which is marketed under the registered Trademark "FLUTTERFREE®".

It is a further object of the present invention to provide such devices wherein the diffuser employed is that which is marketed under the registered Trademark "SKYLINE®".

It is a further object of the present invention to provide such devices wherein the diffuser employed is that which is marketed under the registered Trademark "QRD®".

It is a further object of the present invention to provide such devices wherein the diffuser consists of a compound curved surface.

It is a yet further object of the present invention to provide such devices wherein the diffuser may be of any shape or configuration suitably modified through the provision of holes or slots in desired areas.

It is a still further object of the present invention to provide such devices wherein the locations of holes and/or slots and their total volume as compared to the surface area of the diffuser are chosen to "tune" the device so that it has a desired cut-off frequency between absorption and diffusion.

These and other objects, aspects and features of the present invention will be better understood from the following detailed description of the preferred embodiments, when read in conjunction with the appended drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a front-side perspective view of a diffuser sold under the registered Trademark "FLUTTERFREE®" and modified in accordance with the teachings of the present invention.

Figure 2 shows a left side view of the modified diffuser of Figure 1.

Figure 3 shows a front view thereof.

Figure 4 shows a top view thereof.

Figure 5 shows a front view of the "FLUTTERFREE®" diffusive-absorptive device with detail as to a particular configuration of holes.

Figure 6 shows a rear view of the device shown in Figure 5.

Figure 7 shows a cross-sectional view along the line 7-7 of Figure 5.

Figure 8a shows a top view of a two-dimensional "SKYLINE®" diffuser modified in accordance with the teachings of the present invention.

Figure 8b shows examples of shapes of regions on the surface thereof.

Figure 9 shows a front view thereof.

Figure 10 shows a side view thereof.

Figure 11 shows a perspective view of a "QRD®" diffuser modified in accordance with the teachings of the present invention.

Figure 12 shows a front view thereof.

Figure 13 shows a cross-sectional view along the line 13-13 of Figure 12.

Figure 14 shows a perspective view of a compound curved diffuser modified in accordance with the teachings of the present invention to provide some absorption and a frequency cut-off between absorption and diffusion.

Figure 15 shows a graph depicting the combined absorption and diffusion of a device made in accordance with the teachings of the present invention.

SPECIFIC DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference is first made to Figures 1-7 so that a description of a first embodiment of the present invention may be made.

With reference to Figures 1-7, a first embodiment of the present invention is generally designated by the reference numeral 10 and is seen to include a generally rectangular body 11 having a plurality of forward facing wells that are vertically elongated and have differing depths according to a calculated pattern designed to optimize diffusion. The wells are designated by the reference numerals 12, 13, 14, 15, 16 and 17.

As best seen in Figures 1 and 4, the device also includes three rearward facing wells 18, 19 and 20.

With reference to Figure 3, an example of the modification of the device 10 as previously used solely as a diffuser is seen to include a plurality of holes 21 of generally rectangular shape formed at spaced intervals along the wells 13 and 16. As best seen in Figure 4, an absorptive covering 13 is placed rearward of the device 10 so that sound waves traveling through the holes 21 are suitably absorbed. The material for the absorptive covering 23 may be, for example, fiber glass, mineral wool or foam. A further

example of a pattern of holes formed in a diffuser is illustrated in Figures 5-7, wherein a "FLUTTERFREE®" diffuser 10' is seen to include vertically elongated wells 12', 13', 14', 15', 16' and 17'. In the example shown, it is seen that the wells 13' and 16' each have a plurality of relatively large holes 25 therethrough, while the wells 12', 14', 15' and 17' have rows of relatively small holes 27 therethrough. This pattern of holes as extending through the rear surface of the device 10' is seen with reference to Figure 6. As seen in Figure 7, an absorptive covering 23' is provided on the rear face of the device 10' to absorb any sound waves emanating through the holes 25, 27. The holes 27 may be considered micro-perforations.

With reference, now, to Figures 8a-10, a two-dimensional diffuser known by the registered Trademark "SKYLINE®" is generally designated by the reference numeral 30 and is seen to have sides 31, 33, a top side 35, and a bottom side 37. The "SKYLINE®" diffuser is disclosed and claimed in U.S. Patent 5,401,921 issued September 5, 2000. As seen in particular in Figure 8a, a plurality of rectangular regions 39 are separated by slots 41 formed therebetween to form a grid pattern. The rectangular regions shall include but not be limited to shapes described by reference numerals 39a-e (See Figure 8b). In accordance with the teachings of the present invention, with reference to Figures 8a-10, openings 43 are created in the slots 41 at spaced locations

therein, which openings 43 extend through to the rear surface 45 of the device 30. As best seen in Figures 9 and 10, an absorptive device 47 is mounted on the rear surface 45 of the device 30 to absorb any sound waves that travel through the openings 43.

With reference to Figures 11-13, a "QRD®" diffusor is generally designated by the reference numeral 50 and includes a generally rectangular cubic body 51 having elongated wells 53, 54, 55, 56, 57 and 58 formed therein. As seen in Figure 12, rectangular openings 59 are formed in the wells to allow sound to travel therethrough to the rear surface of the diffusor. The holes 59 may be provided in a vertically spaced pattern in each of the wells.

In addition, small sized holes 61 may suitably be provided. As best seen in Figure 13, the rear surface 63 of the device 50 is covered by an absorbent material covering 65 designed to absorb sound waves traveling through the holes 59 and 61.

Figure 14 depicts a compound curve-shaped diffuser 70 that may be modified in accordance with the teachings of the present invention as exemplified in Figures 1-13 through the provision of any desired pattern of holes, slots or openings extending through to the rear surface thereof, which rear surface may suitably be covered by a sound absorbing material as should be understood from the teachings of the present invention as explained with reference to Figures 1-13.

Figure 15 shows a graph depicting absorbent coefficient and diffusion coefficient with frequency, which shows a cut-off frequency of about 1100 Hz between absorption and diffusion. In the graph of Figure 15, if the configuration of absorption and diffusion is desired as shown in Figure 15, the inventive device is appropriately "tuned" to provide a cut-off frequency of about 1100 Hz so that below 1100 Hz absorption takes place and above 1100 Hz diffusion takes place.

As explained above, by example through the embodiments illustrated in Figures 1-14, the perforations through a front surface of an existing diffuser enable resonant absorption to take place using the well known mechanism of a Helmholtz resonator. The essential parts of absorptive sections comprise perforations opening up to a cavity. The cavity is defined by the enclosed volume. The air in the slots or holes vibrates as a mass against the spring formed by the trapped air in the cavity. To make absorption efficient, absorptive material is provided in the cavity behind the slots or holes and, as explained above, may be made of a suitable absorptive material such as, for example, mineral wool, fiber glass or foam. Resistance can also be provided by using small hole sizes such as those shown with reference to Figures 5 and 6, the holes 27. Where holes such as the holes 27 are used, and sometimes described as "micro-perforations", it may be possible

to eliminate the absorptive material 23' shown in Figure 7 or, at least, to use a lesser thickness thereof.

As should be understood by those skilled in the art, the exact construction of a Helmholtz absorptive device can be suitably varied to suit manufacturing, acoustic and visual-aesthetic requirements.

The inventive device in all of its embodiments can be "tuned" so that the cut-off frequency between absorption and diffusion is at a desired frequency. Such tuning is accomplished by varying perforation and cavity size. In this regard, the resonant frequency for an absorber is given by the formula:

$$f = \frac{c}{2\pi}\sqrt{\frac{S}{LV}}$$

where c is the speed of sound in air, S is the cross-sectional area of a perforation, L is the depth of the perforated sheet including the end correction to allow for radiation resistance, and V is the enclosed volume in the cavity. By applying this formula and using appropriate trial and error, the correct resonant frequency may be achieved.

In designing embodiments of the present invention, it is also necessary to decide the frequency ranges for absorption and diffusion. This aspect is also shown in Figure 15. Figure 15 shows a graph of absorption and diffusion ranges for the embodiment of Figures 1-4. As clearly seen, below about 1100 Hz, effective

diffusion does not occur because the depth of the front surface of the diffusive aspect of the device is too small to sufficiently perturb the wave front. Thus, below about 1100 Hz, the Helmholtz-type resonator is "tuned" to absorb sound.

It is a significant advance to provide a single device that effectively diffuses sound waves above a cut-off frequency, and absorbs sound waves below that frequency.

While the present invention has been described in terms of several examples of diffusers, the present invention is not limited to those particular examples. Examples of diffusers that may be modified in accordance with the teachings of the present invention include but are not limited to optimized simple or compound curved surfaces, stepped and optimized phase grating diffusers, arcs, ellipses, and pyramids. The exact topology may be suitably varied to suit manufacturing, visual and acoustic requirements.

Accordingly, an invention has been disclosed in terms of preferred embodiments thereof which fulfill each and every one of the teachings of the present invention and provide new and useful embodiments of sound diffuser with low frequency sound absorption of great novelty and utility.

Of course, various changes, modifications and alterations in the teachings of the present invention may be contemplated by those skilled in the art without departing from the intended spirit and scope thereof.

As such, it is intended that the present invention only be limited by the terms of the appended claims.

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